62

ABSORPTION OF ULTRA HIGH FREQUENCY WAVES IN SALT SOLUTIONS

By S. K. CHATTERJEE AND B. V. SREEKANTAN

(*Received for publication, April 23, 1948*)

ABSTRACT. Absorption of ultra high frequency electromagnetic waves by aqueous solutions of $MgCl_2$, $CuSO_4$, and KCl has been experimentally studied. Result indicates two absorption peaks for coppersulphate solution but one absorption peak for magnesium chloride and potassium chloride solutions over the frequency range 300 to 500 Mega cycles. Absorption maxima shift towards higher concentration for higher frequencies for all the solutions. The average values for the product of normality at which maximum absorption takes place and corresponding wave length are 11.96, 8.648 and 15.96 for $MgCl_2$, $CuSO_4$ and KCl respectively. The observed relaxation time shows values lower than the theoretical values for all the solutions. Radius of rotor calculated from the observed values of relaxation time for the solutions indicate that the absorption is due to the ionic atmosphere rotating as a whole under high frequency stress.

EXPERIMENTAL

Description of equipments and experimental technique have been published elsewhere (Chatterjee and Sreekantan, 1948). The percentage of absorption

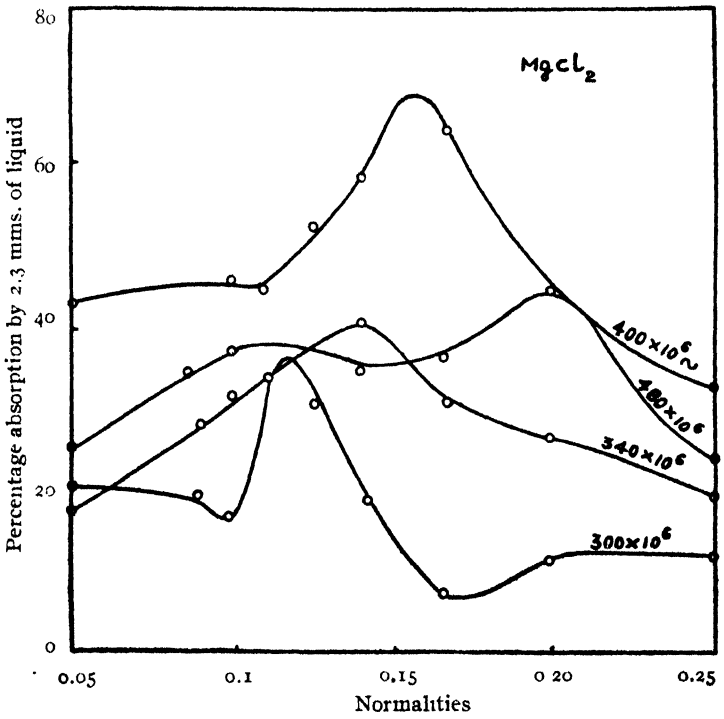

FIG 1

suffered by an electromagnetic wave (300-500 Mc/s) while passing through aqueous solutions of magnesium chloride, copper sulphate, and potassium chloride of different concentrations is shown in Figs. 1 to 3.

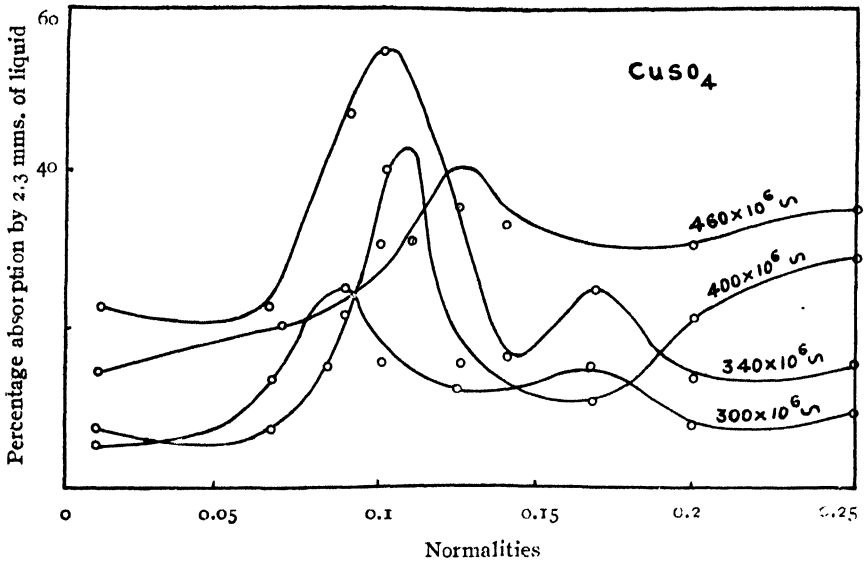

FIG 2

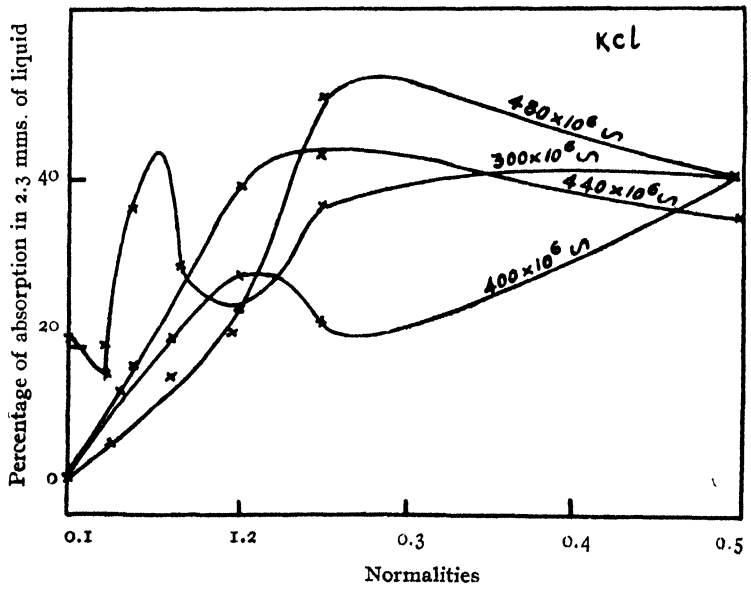

FIG 3

DISCUSSION

From the results of experiment the following facts are significant :—

(1) The absorption peak for all the solutions shifts towards higher concentration with increasing frequencies.

(2) For copper sulphate solution, at all frequencies within the range considered, two distinct peaks separated by a plateau are noticed. It is further observed that the distance between two peaks on the normality axis tends to increase as the frequency of electric stress increases. This shows a similarity with phenomena observed in the case of two tightly coupled circuits where the distance between peaks increases with the coefficient of coupling increasing. In the case of other two solutions only one absorption peak is observed within the frequency range in question.

(3) The product of normality γ^* in gm. equivalent per litre at which absorption maxima occurs and the corresponding wavelength λ maintains an almost constant value, different for different solutions as given in Table I. The average values of the product $\gamma^*.\lambda$ are 11.96, 8.648, and 15.96 for $MgCl_2$, $CuSO_4$, and KCl respectively. It may be mentioned that for copper sulphate solution the values of $\lambda.\gamma^*$ correspond to the first peak.

TABLE I

Frequency in Mc/s.	$MgCl_2$		$CuSO_4$		KCl		Average
	γ^1	$\lambda\ \gamma^1$	γ^1	$\lambda\ \gamma^1$	γ^1	$\lambda\ \gamma^1$	$\lambda.\gamma^*$
300	0.11N	11.00	0.09N	9.00	0.15N	15.00	11.96
340	0.14N	12.31	0.10N	8.82	—	—	($MgCl_2$)
400	0.16N	12.00	0.115N	8.626	0.21N	15.75	8.648
460	—	—	0.125N	8.149	—	—	($CuSO_4$)
480	0.20N	12.50	—	—	0.27N	16.75	15.96(KCl)

The presence of two peaks in the case of copper sulphate solution needs an explanation. This may be attributed to a random variation in the structure of material or this may be explained on the basis of the existence of two relaxation times. The theoretical relation of Debye and Falkenhagen (1934) gives only one relaxation time Θ given by

$$\Theta = \frac{8.85 \times 10^{-11}}{\Lambda_\infty . \gamma^*} . D_o \qquad \ldots \quad (1)$$

corresponding to the existence of one peak only. The existence of one peak is predicted on the Debye's assumption of molecules, spherical in shape rotating in an alternating field. This implies a single region of dispersion and a single relaxation time. The theory of dielectric dispersion has been extended to the case of an ellipsoidal model by Perrin (1934). It has been established that three values of relaxation time are possible in the case of an ellipsoidal

molecule and two values of relaxation time are possible in the case of an ellipsoid of revolution. The experimental curves of copper sulphate solution suggests a complex mode of oscillation which may consist of the rotation of the ellipsoid about the major axis or the oscillation of the major axis itself in an indeterminate plane. In addition to this if we consider that the ellipsoids of revolution are pressed against each other, rotating about or oscillating along the major axis then the viscosity term in the Debye's expression (1929) for relaxation time $\tau = 4\pi\eta a^3/kT$ cannot be evaluated by a macroscopic measurement of viscosity as suggested by Girard and Abadie (1946). The relaxation time observed $\tau_{obs.}$ crrresponding to the absorption peak (Figs. 1—3) has been calculated from the following relation :—

$$\tau_{obs.} = \frac{1}{\omega_{max.}} \cdot \left(\frac{\epsilon_\infty + 2}{\epsilon_{w=0} + 2} \right) = \frac{1}{2\pi f_{max.}} \cdot \frac{8_2}{\epsilon_{w=0} + 2}$$

which can be deduced from the Debye's generalised expression (1929) for the dielectric constant

$$\epsilon = \epsilon' - j\epsilon''$$

The values of the dielectric constant $\epsilon_{w=0}$ at audio frequencies for different normalities can be calculated from the relation (Falkenhagen, 1934).

$$\epsilon_{w=0} - \epsilon_s = \frac{1.97 \times 10^6 \, |Z_1 Z_2| \cdot \{ Z_1 | + | Z_2 | \}^{\frac{1}{2}} \cdot (q\gamma^*)^{\frac{1}{2}}}{2\epsilon^{\frac{1}{2}} \cdot T^{\frac{3}{2}} \cdot \left(1 + \frac{1}{\sqrt{q}} \right)^2}$$

which in the case of different solutions can be reduced to the following experessions.

$$\left(\epsilon_{w=0} - \epsilon_s \right)^{23°C}_{CuSO_4} = 28.95 \sqrt{\gamma^*}$$

$$\left(\epsilon_{w=0} - \epsilon_s \right)^{23°C}_{MgCl_2} = 9\ 281 \sqrt{\gamma^*}$$

$$\left(\epsilon_{w=0} - \epsilon_s \right)^{23°C}_{KCl} = 3.51 \sqrt{\gamma^*}$$

where ϵ_s may be taken as 80, the dielectric constant of water at u.h.f. The theoretical values of $\tau_{cal.}$ have been arrived at from the expressison for the ionic relaxation time given in equation (1) where the values of conductivity at infinite dilution Λ_∞ are as follows

$(\Lambda_\infty)MgCl_2 = 110.88$, $(\Lambda_\infty)CuSO_4 = 113.85$, $(\Lambda_\infty)KCl = 130.1$

A comparative study of $\tau_{obs.}$ and $\tau_{cal.}$ in the case of the three solutions can be made from Table II.

TABLE II

Frequency in Mc/s.	$MgCl_2$		$CuSO_4$		KCl	
	$\tau_{obs.} \times 10^{10}$ secs.	$\tau_{cal.} \times 10^{10}$ secs.	$\tau_{obs.} \times 10^{10}$ secs.	$\tau_{cal.} \times 10^{10}$ secs.	$\tau_{obs.} \times 10^{10}$ secs	$\tau_{cal.} \times 10^{10}$ secs
300	5.114	5.672	4.888	6.913	3.692	5.220
340	4.490	4 561	4.212	6 220	—	—
400	3 806	3 991	3.555	5.411	2 646	3 902
460	—	—	3 076	4.977	—	—
480	3.156	3 193	—	—	2.063	3.245

It will be observed that $\tau_{obs.}$ in each case is lower than $\tau_{cal.}$ This divergence may be due to the complexity of real facts. It may be ascribed to the fact that the value for ionic relaxation time given by equation (1) has been deduced on the assumption of Debye's theory, which is applicable for solutions more dilute than those used in the present investigation.

The occurrence of absorption maxima may be explained due to the rotation of ions or ionic atmosphere as a whole, when the solution is subjected to an ultra high frequency electromagnetic wave. To determine whether it is due to ionic rotation or the rotation of the ionic atmosphere as a whole the radius of the rotor has been calculated from the following relation (Debye, 1929).

$$\tau = \frac{4\pi\eta a^3}{kT}$$

where η is the viscosity of the solution. The values of relative viscosity η_r for different solutions at different concentration are given in Table III (Ruby and Kawai, 1926). The volume of the rotor has been calculated using the following relation which holds both for a spherical and an ellipsoidal rotor as shown by Potapenko (1948).

$$\text{Volume } (V) = \frac{\tau kT}{3\eta}$$

The values are given in Table III.

TABLE III

η_r = Relative Viscosity—Viscosity of water = 8.94 millipoises, at 25° C.

Electrolyte	Normality	Relaxation time $\times 10^{10}$ secs.	η_r	$a \times 10^8$ cms.	$v \times 10^{22}$ c.c.	$a_1 \times 10^8$ cms.	Ionic radius $\times 10^8$ cms.
$MgCl_2$	0.200N	3.156	1.075	4 776	4.474	3.953	0.65 (Mg ion) 1.81 (Cl ion)
	0.160N	3 806	1.062	5 075	5.464	4 414	
	0.110N	5.144	1.040	5.633	7.496	5.330	
$CuSO_4$	0.125N	3.076	1.072	4.697	4.344	4.380	0.96 (Cu ion)
	0 115N	3.555	1.065	4.918	5.578	4.512	
	0.090N	4.888	1 050	5.533	7.096	5.101	
KCl	0.270N	3 245	0.9993	4.896	4.917	5.865	1.33 (K ion) 1.81 (Cl ion)
	0.210N	3.902	0.9996	5.206	5.910	6.665	
	0.160N	5.220	1.000	5.736	7.902	7 870	

In the last column of the above tables value of ionic radii, as given by Pauling (1939), are given for the sake of comparison. It will be observed that the calculated values of radius of the rotor agree more closely with those calculated using the following relation (Falkennagen 1934) for the radius of the ionic atmosphere.

$$a_i = \frac{4{\cdot}31 \times 10^{-8}}{\{\gamma \sum \gamma_i Z_i^2\}^{\frac{1}{2}}}$$

It may therefore be concluded that the absorption maximum observed in the case of aqueous solutions of electrolytes in the frequency range under consideration (300 to 500 Mc/s) is due to the rotation of the ionic atmosphere as a whole.

ACKNOWLEDGMENT

The authors wish to express their grateful thanks to the Head of the department for the facilities given to carry out the above investigation.

DEPARTMENT OF ELECTRICAL COMMUNICATION ENGINEERING,
INDIAN INSTITUTE OF SCIENCE,
BANGALORE.

REFERENCES

Chatterjee, S. and Sreekantan B. V., 1948, *Ind. Jour Phy.*, **22**, 229.
Debye, P. 1929, 'Polar Molecules' Chemical Catalog Co., New York.
Falkenhagen, H., 1934, 'Electrolytes,' p. 213.
Falkenhagen, H., 1934, Electrolytes,' p. 219.
Falkenhagen. H., 1934, 'Electrolytes,' p. 106.
Girard, P. and Abadie 1946, *Trans. Far. Soc.*, **52A**, 'Dielectrics,' 10.
Perrin, J., 1934, *Phys. et Rad*, **5**, 497.
Potapenko and Wheeler, D, 1948, *Rev. Mod. Phy.*, **20**, 143.
Pauling, L. 1939 'Nature of the Chemical Bond and the structure of molecules and crystals,' p. 326.
Ruby, C., and Kawai J., 1926, *Jour. Chem. Soc.*, **48**, 1119